USE OF TSS AS A NEUTRAL FORMAT FOR GEOMETRY MODEL CONVERSIONS: AN ALTERNATIVE TO STEP-TAS

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ABSTRACT

In today's spacecraft industry, multi-national projects are becoming more common, requiring a sharing of models across different platforms and formats. Companies and organizations in the United States have a wide range of radiative/geometry modelers from which to choose, including: TSS, TRASYS, Thermal Desktop, TMG, NEVADA, and FEMAP, to name a few. Similarly, European companies choose primarily between ESARAD and Thermica. With each company working in a preferred geometry modeler, the task of integrating each of the subcomponents into a single model and format becomes increasingly difficult.

Recently, the European Space Agency has made efforts to develop a compatible neutral format for the exchange of thermal models called STEP-TAS. Unfortunately, STEP-TAS is not yet ready for widespread use. In the meantime, thermal analysts must use existing tools or manually convert the model to the desired format. Given the detail and complexity of today's models, this can be a time consuming and demanding task.

Swales Aerospace has been involved in a number of international cooperative projects including MetOp, SECCHI, EOS-Aura, and EIS. Each of these NASA projects has required model conversion to a single consistent format for the spacecraft provider. For MetOp, Swales frequently needed to convert TSS models to ESARAD. For the SECCHI (STEREO Mission) and EOS-Aura projects, it was necessary to convert a Thermica model to TSS for internal use. The reverse was needed for the EIS project where a TSS model was converted to Thermica.

While it is generally agreed that the use of a neutral format is the best approach, opinions vary on which neutral format is best. TSS was selected as a neutral format for the necessary conversions, given Swales' familiarity with its capabilities and its prevalence in the US aerospace industry. Through the aforementioned projects, Swales has developed Visual Basic algorithms to convert ESARAD and Thermica to TSS and back. While the primary focus has been conversion to and from European modeling tools, the capabilities exist to interface to any other ASCII format.

The use of TSS as a neutral format for geometry model conversions and the subsequent development of the conversion algorithms has saved a significant amount of time and money. This paper seeks to highlight some of the capabilities of the algorithms and document some case studies in which the algorithms were used. Allowing the computer to convert the geometry models allows for a more efficient turn around time of model submission. In turn, this allows the thermal engineer to focus on more important analysis tasks, rather than spending resources converting geometry models.

1 Introduction

It can be a difficult and time-consuming task for a thermal analyst to integrate many subsystem thermal models into a system level spacecraft model, particularly if the thermal models are not in the same format. Since the aerospace industry does not have a single, industry-standard analysis code for thermal radiation modeling, conversions are often necessary to create the integrated spacecraft level model. Each company or agency is free to use whatever tools are available or familiar, unless specified by a particular project. Unfortunately, for cooperative international projects, it is often difficult to convince all parties involved to adopt one particular platform and software package. This often leads to an instrument contractor developing a model in their preferred software and eventually having to convert to another format for incorporation into a spacecraft model. The responsibility of this does not always fall on the instrument provider, particularly if it has not been contractually specified. Currently, a very limited number of converters exist and most of these are aimed at conversion from one specific format to another and do not utilize a neutral file.

This paper highlights some of the major differences between thermal model formats focusing on TSS, ESARAD, and Thermica. A short description of the most common thermal radiation codes as well as the differences in entity representation, what entities are available, and the nodalization are discussed. Examples of tasks performed by Swales Aerospace that required thermal model conversion are presented including the MetOp, SECCHI, OMI, and EIS programs.

2 Software

Numerous thermal radiation modelers are commercially available in today's market. These include NASA developed codes, ESA developed codes, and independently developed codes. These codes all have similarities; each of them provides a base set of primitive shapes (e.g. rectangle, cones, triangles, etc) and parameters that define location, size, orientation, active sides, optical properties and thermal nodes. Since some of these parameters are specific only to thermal analyses, it makes the use of existing FEA neutral file formats (e.g. IGES, STEP, FEMAP) difficult. The most prevalent radiation solver codes are discussed hereafter.

2.1 TSS

The Thermal Synthesizer System (TSS) was developed by NASA to replace and correct a number of issues and problems from the old TRASYS code and is now commercially available and maintained by SpaceDesign. TSS produces an ASCII geometry file with a hierarchical listing of all surfaces and assemblies in a model. The geometrical representation of a TSS surface is done through X, Y, and Z translations, followed by 3 Euler rotations about any of the subsequently transformed X, Y, or Z axes. Lastly, surface specific parameters (e.g. xmin, radius, etc) define the object in 3D space.

2.2 ESARAD

ESARAD is the primary radiation analysis code used by ESA. It was developed by Alstom to provide a single, robust code for all ESA contractors. ESARAD does not provide a hierarchical listing, but instead defines a collection of user-defined objects (SHELLs). Each SHELL has specific properties, including up to 6 points, which define the location and size in 3D space of the object. Multiple SHELLS can be grouped together to form assemblies, which may then be further rotated or translated. These assemblies may then be further grouped together to form the model hierarchy.

2.3 Thermica

Thermica was developed by Matra Marconi (now Astrium) and is the primary competitor to ESARAD in Europe. It has found widespread use in organizations that were formerly Matra Marconi and did not necessarily interface to ESA. Thermica, like TSS, also provides a hierarchical listing of thermal objects, where an object identifier defines the location in the model hierarchy.

2.4 Thermal Desktop

Thermal Desktop was developed by Cullimore and Ring. It creates and displays surfaces, and performs radiation and thermal analysis, within the AutoCAD environment. As such, the format where the entities and properties are stored is a proprietary, compressed, binary format, and not accessible to an external program.

2.5 TMG

TMG was developed by Maya Heat Transfer Technologies as a complete radiation and thermal analysis package, with strong support for finite element analysis. Since element types are different from the surface types in most other codes, it is often difficult to smoothly transition to and from TMG.

2.6 TRASYS

TRASYS is legacy code developed by NASA for radiation analysis. It has seen a decline in usage recently with the availability of more advanced tools. However, it is still a format to which many newer codes can export or import, therefore is survives as a "neutral" format for thermal model exchange.

2.7 Existing Converters

Table 1 highlights the available converters provided with each of the major codes.

Table 1 – Existing Converters Supported by Various Codes

Code	Imports	Exports	Primary User
TSS	TRASYS	TRASYS	United States
ESARAD	SET-ATS, STEP-TAS	SET-ATS, STEP-TAS	Europe
Thermica	SET-ATS, STEP-TAS	SET-ATS, STEP-TAS	Europe
Thermal Desktop	TSS, TRASYS, STEP-TAS	TSS, TRASYS, STEP-TAS	United States
TMG	TSS	TSS, TRASYS	United States
TRASYS	NONE	NONE	United States

As shown in Table 3, either TSS or TRASYS is supported as an import/export option for the majority of the codes used in the United States. Similarly, the European codes both import and export STEP-TAS and SET-ATS. However, no other tools exist to convert between European software (ESARAD and Thermica) and United States software (TRASYS, TSS, TMG, and Thermal Desktop). Unfortunately, support of competitors' software and formats is usually not a high priority to software development companies.

3 Conversions

Conversion from one format to another requires consideration of three aspects of a surface definition: geometry, optical properties/active sides, and thermal node numbering. Of these three, the geometry is often the most difficult to convert, since each code has its own unique method of surface definition.

3.1 Geometry

Geometry parameters consist of dimensions and angles defining the overall size and shape of the entity and may also include rotations and translations to position the surface in 3D space. These values may be explicitly defined or indirectly specified by the point definitions. Each code supports a base set of surface types and methods for defining them. However, not all codes support all surface types.

3.2 Representation

Each entity can be represented by a collection of points, parameters, or a combination of the two. Unfortunately, each software package has its own way of defining an object, making direct conversion difficult. A point based system may not have directly available the parameters needed to define the same object in another code. An example of the definition for a truncated, partial cone is shown in Figure 1 for TSS, ESARAD, and Thermica.

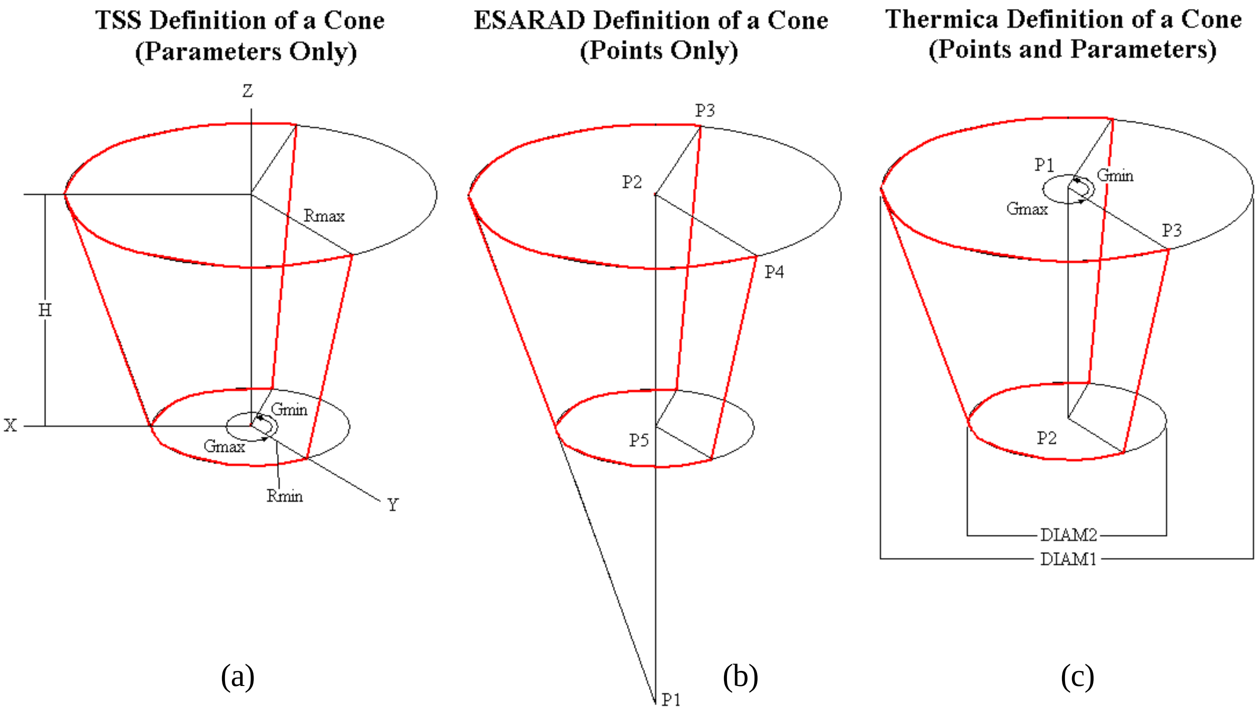

Figure 1 – Representations of a Truncated, Partial Cone in TSS, ESARAD, and Thermica

Parameters define the surfaces and its orientation through a series of predefined fields. These may include translations, rotations, and dimensions (e.g. xmin, radius, height, etc). This is the primary method used by TSS to define each object. For a cone in TSS the following parameters must be specified to fully define the object: H, Rmin, Rmax, Gmin, and Gmax, (See Figure 1a)

Point representation defines the size and orientation of a surface using a series of pre-defined points in 3D space. While this is easy to define for a rectangle or triangle, revolved surfaces (disc, cylinder, cone) are not as clearly defined. This is the primary method used by ESARAD to define each object. In the ESARAD cone example P1, P2, and P3 must be specified to define a cone. P4 and P5 are used to define a partial revolution and truncation respectively. (See Figure 1b)

Thermica and Thermal Desktop utilize both points and parameters to define each surface. The points are used to specify the orientation and location, and the parameters to specify the dimensions. For a Thermica surface, the example above would require definition of P1, P2, P3, DIAM1, DIAM2. Gmin and Gmax are used to define a partial revolution. (See Figure 1c)

3.2.1 Surface Types

Each code has a base set of primitive surface types listed in Table 2 along with how they are defined.

Table 2 – Method of Entity Definition for Common Entities

Type	TSS	ESARAD	Thermica	Thermal Desktop**	TMG
Rectangles	Params	Pts or Params	Pts	Pts and Params	Pts
Triangle	Pts	Pts	Pts	**Not Available***	Pts
Disc	Params	Pts or Params	Pts and Params	Pts and Params	**Not Available**
Cylinder	Params	Pts or Params	Pts and Params	Pts and Params	**Not Available**
Cone	Params	Pts or Params	Pts and Params	Pts and Params	**Not Available**
Quad	Pts	Pts or Params	Pts	**Not Available***	Pts
Polygon	Pts	**Not Available**	**Not Available**	Pts	**Not Available**
Ellipse	Params	**Not Available**	Pts and Params	Pts and Params	**Not Available**
Paraboloid	Params	Pts or Params	Pts and Params	Pts and Params	**Not Available**
Sphere	Params	Pts or Params	Pts and Params	Pts and Params	**Not Available**
Box	Params	Pts or Params	Params	**Not Available**	Pts

* Can be represented by polygon entity type ** Data not available in ASCII format

TSS provides only a parameter based entity definition for most of the primitives, with the exception of triangles, polygons, and quadrilaterals. ESARAD provides both a parameter and a point method of entity definition, with the point definitions more commonly used. In Thermica and Thermal Desktop, primitive definition consists of both points (to define the coordinate system) and parameters (to define the size). TMG is a finite element based code and does not support element types other than planar triangles and quadrilaterals and solid elements.

3.3 Optical Properties, Active Sides, and Nodalization

Thermal radiation codes also include optical properties for use in calculating the radiation exchange factors between surfaces and the environmental energy absorbed by a surface. These may or may not include specular behavior. In addition, the activity (whether it is included in the radiation exchange) of each side must also be defined.

Each surface is assigned one or more node numbers, which are referenced by the thermal model solver (e.g. SINDA, ESATAN, etc). If multiple nodes are specified then the surface is subdivided into smaller subsets. This subdivision may be in one or two directions and may or may not be of uniform spacing. In addition, the node numbers may or may not follow a specific pattern or increment depending on the code. ESARAD and Thermica require a pattern, specifying an initial node number and an increment. TSS allows the user to specify the node number for each subdivision. In addition, TSS and ESARAD allow a user to specify different nodes for the front and back sides of a surface, while Thermica does not.

4 Examples

Swales has been involved in a variety of projects that have required either converting a model submitted in a foreign format (ESARAD, Thermica) or delivery of a model in a foreign format. Each of these has justified the development of a computer software tool to automate the conversion process. Routines were developed in Visual Basic to convert from TSS to ESARAD and from ESARAD to TSS for the MetOp project. For the SECCHI and OMI projects, a routine was developed to convert from Thermica to TSS. Lastly, for EIS, a routine was developed to convert from TSS to Thermica.

4.1 MetOp

The MetOp project required all instrument geometry model deliveries to be in ESARAD for incorporation into the spacecraft model. Models were received from instrument contractors in either TSS or TRASYS formats. Using the existing TRASYS to TSS converter, it was a simple matter to generate TSS models for each of the seven instruments.

Given the predicted frequency of model updates, model complexity, and number of models to convert over the duration of the project, it was deemed more efficient to automate the model conversion rather than to manually recreate the models each time a new delivery was submitted. A routine was developed in Visual Basic to read in and store all the surface parameters and hierarchy from a TSS geometry file. These values were then processed to determine the local points for each surface and these points subsequently transformed to the global coordinate system based on the rotation and translation operations for the child surface and its parent(s). The points generated correspond to the ESARAD point definitions for each respective entity type. However, a number of inconsistencies (listed in Table 3) exist between TSS and ESARAD and code was included to solve these issues. Figure 2 shows the AMSU-A2 instrument for Metop.

Table 3 – Discrepancies when converting from TSS to ESARAD

Feature	TSS	ESARAD	Workaround
Ellipse Entity Type	Yes	No	Polar Array of triangles
Non-sequential node numbering	Yes	No	Creation of separate entities
Non-uniform nodalization	Yes	No	Creation of separate entities
Optical Properties defined in same file as geometry	No	Yes	Create optics within output file
Variable length units	Yes	No	Convert all sizes to user defined units
Box Entity is one node	Yes	No	Assign node increment of zero
Node Label as surface property	No	Yes	Uses TSS entity name

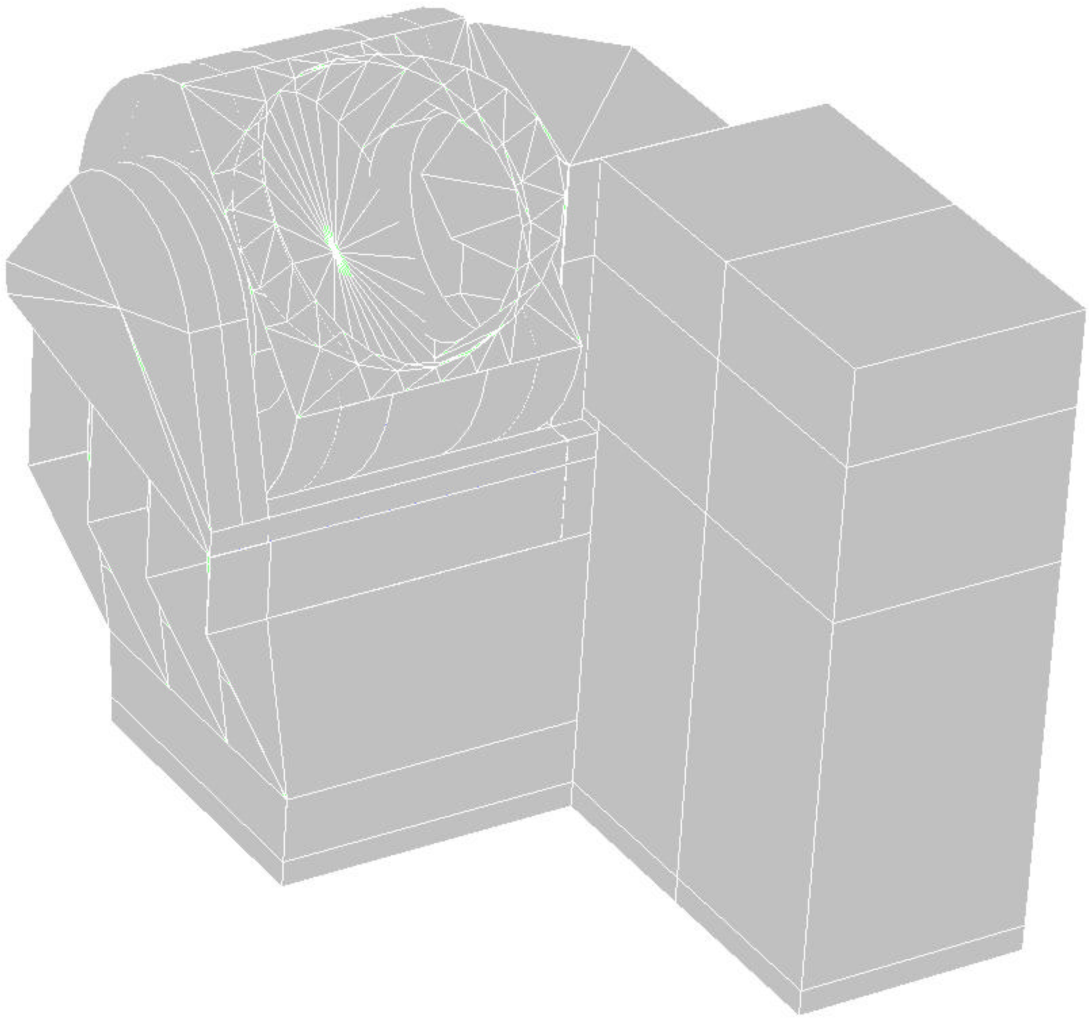

Figure 2 – Detailed AMSU-A2 TSS model for MetOp

During one point in the project, the visualization capability of ESARAD was not functional on any of the platforms available at Swales, making visualization of the models impossible. In order to continue work until the issues were corrected, a routine was developed to convert the ESARAD spacecraft model and its hierarchy of submodels to TSS. Again, inconsistencies were encountered and resolved. These are listed in Table 4.

Table 4 – Discrepancies when converting from ESARAD to TSS

Feature	ESARAD	TSS	Workaround
Cutting operations supported	Yes	No	Cutting entities created for reference
Copy operations supported	Yes	No	Create new entity by copying base entity
Update of entity properties after entity definition	Yes	No	Search through model tree and modify property
External submodels and/or files may be included in top level model	Yes	No	Insert entities from submodel at proper location
Extensive use of variables allowed	Yes	No	Storage of variables and values and evaluation of expressions

Each of these discrepancies is automatically handled by the routine with the exception of entity type conversion. The routine allows the user to specify which entity types should be converted (e.g. ellipse to polar array of triangles). The TSS to ESARAD routine has been in use for approximately 4 years with excellent success. It has saved countless man-hours by automating the task of model conversion, significantly reducing the turn-around time between model receipt from the instrument contractor, conversion, and model delivery to the spacecraft contractor. The ESARAD to TSS routine was only used for a short duration until the ESARAD software was updated to correct the visualization errors, but during that time operated successfully.

4.2 SECCHI and OMI

For the SECCHI and OMI projects, models were received in a Thermica format. Since Thermica is not available at Swales, it was necessary to convert to a more familiar tool for internal analysis with SECCHI. A requirement of the spacecraft contractor was delivery of all models in TSS format, therefore, the OMI model had to be converted. Table 5 lists some of the discrepancies encountered when converting from Thermica to TSS.

Table 5 – Discrepancies when converting from Thermica to TSS

Feature	Thermica	TSS	Workaround
Non hierarchical order of entity input	Yes	No	Re-sort entities by object identifier
Multiple surfaces assigned to single entity	Yes	No	Create assembly containing surfaces
ANGLE1 allowed to be greater than ANGLE2 (i.e. Min > Max)	Yes	No	Add 360° to ANGLE2
Node numbering may be clockwise or counterclockwise for revolved surfaces	Yes	No	Define node_ids appropriately (not yet implemented)
Extensive use of variables allowed	Yes	No	Storage of variables and values and evaluation of expressions
Optical Properties defined in geometry file	Yes & No	No	Both methods of property definition read and output to single optics file

Figure 3 shows the TSS model for SECCHI after conversion from Thermica and provides a good example of the complexity of models that can be accommodated by these routines. This routine also automatically handles all of the above-mentioned discrepancies (with the noted exception). It has only been recently developed, but has met with success on a limited number of test cases, saving a significant amount of time compared to manual conversion.

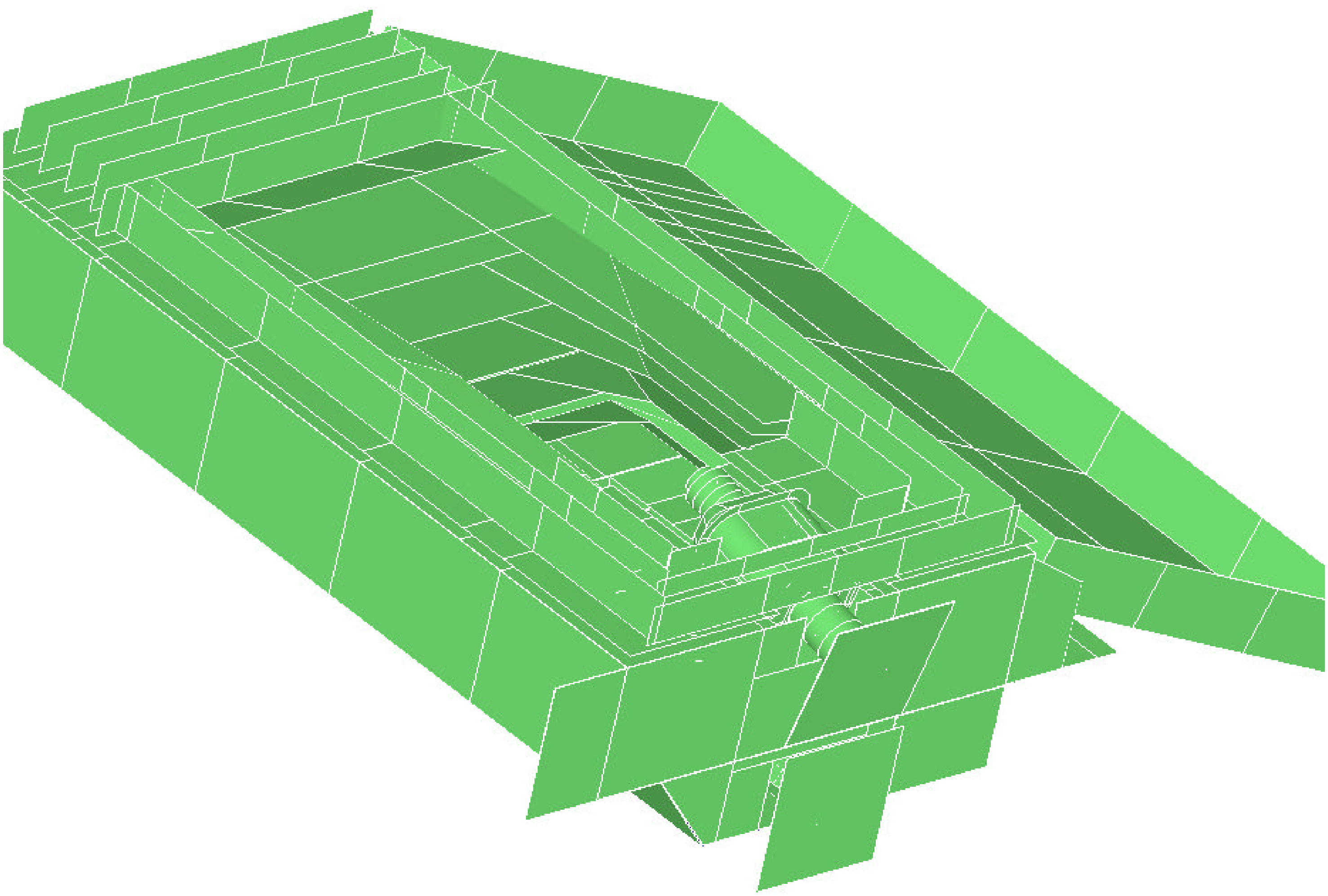

Figure 3 – TSS Model of SECCHI Spacecraft after Conversion from Thermica

4.3 EIS

For the EIS project, it was necessary to deliver a model in Thermica format to the University of Birmingham. This presented a reverse of the efforts for SECCHI and OMI, since conversion from TSS to Thermica was now required. Discrepancies encountered when converting from TSS to Thermica are listed in Table 6. An image of the EIS Clamshell door is depicted in Figure 4.

Table 6 – Discrepancies when converting from Thermica to TSS

Feature	TSS	Thermica	Workaround
Non-sequential node numbering	Yes	No	Creation of separate entities
Non-uniform nodalization	Yes	No	Creation of separate entities
Optical Properties defined in same file as geometry	No	Yes & No	All properties written to geometry file
Variable length units	Yes	No	Convert all dimensions to user specified units
Double Sided surfaces (2 nodes)	Yes	No	Creation of two surfaces with small gap

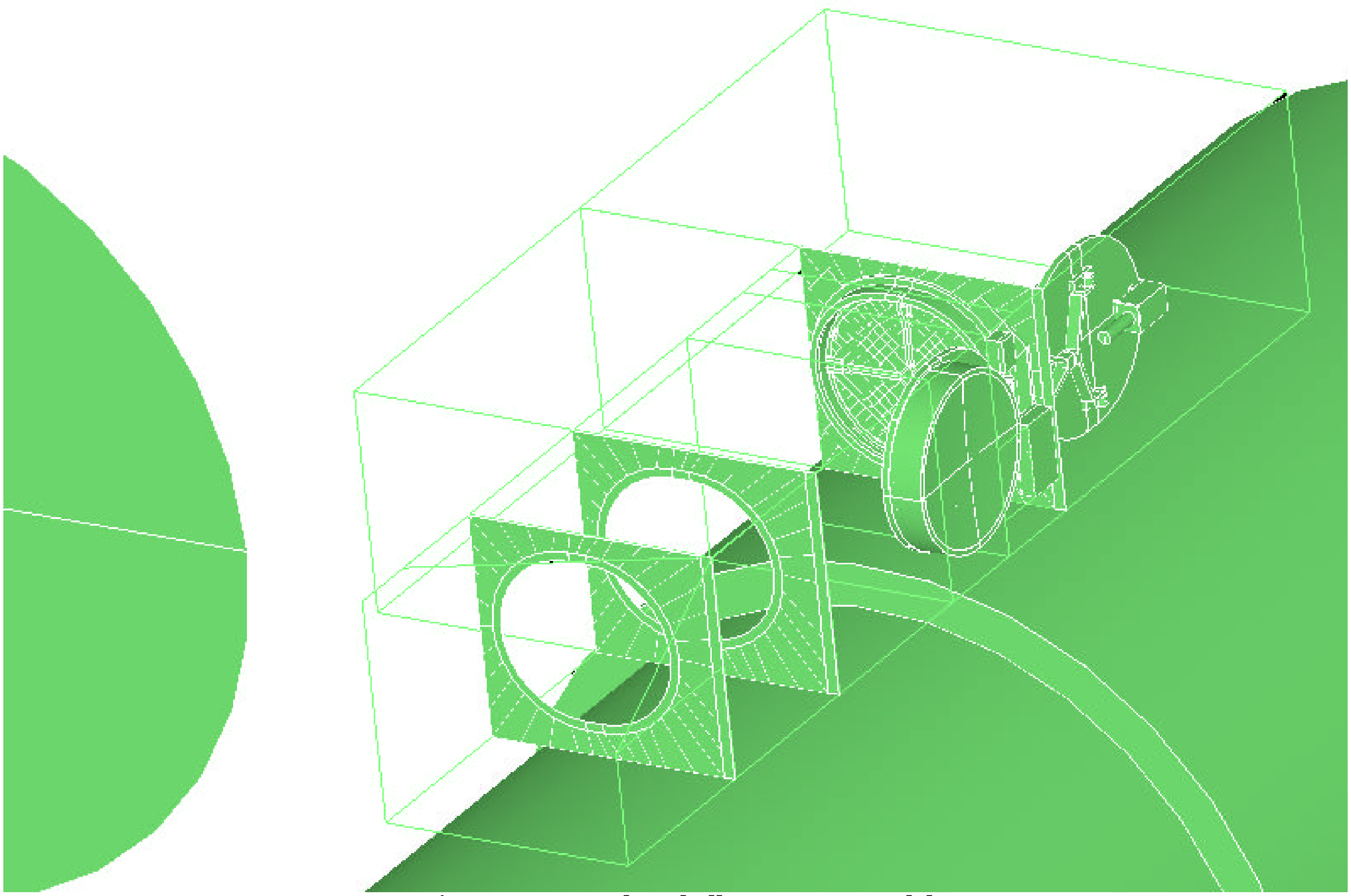

Figure 4 – EIS Clamshell Door TSS Model

This routine provided a unique challenge since there was no way to verify the converted model since Swales does not have a copy of Thermica. To test its success, the converted Thermica model was reconverted back to TSS using the routine from SECCHI and OMI and the resulting model was compared to the original TSS model. Based on these comparisons and the known discrepancies (units and double sided surfaces), the double conversion (TSS to Thermica to TSS) did result in a model that was representative of the original. However, Thermica had some issues with the converted files that the Thermica to TSS routine did not. This required a few iterations with the University of Birmingham but eventually resulted in a valid Thermica model

5 Future Plans

Further development may be undertaken to support TRASYS and possibly Thermal Desktop. The ability to read in any format and process it as if it were a TSS model also lends itself to the development of additional utilities to evaluate models. So far, programs have also been developed to modify optical property names and remove unused properties, output useful property information for each entity to a table, and add instrument specific prefixes to entity names to prevent conflicts when integrating multiple instruments.

In the future, the software could provide a link between a 3D point in space (located on an object), the thermal node of that object, and the temperature of that node. This may greatly aid in a STOP (Structural-Thermal-Optical-Performance) analysis, since a disconnect usually exists between mechanical models and thermal models. This will allow a temperature assigned to a point in space to be mapped to an existing FEA mesh on a mechanical model.

There are also plans to develop a geometry builder/viewer capable of reading and writing any ASCII based format all within a common environment. This would allow a user to develop the model within a common environment and use the solver of choice for the actual radiation analysis. It would also facilitate the quick delivery of models in other formats.

6 Conclusions

The development of routines to automate the conversion of geometry models between Thermica, ESARAD, and TSS has saved countless hours of manual effort. The development and use of these routines has allowed Swales to quickly accept models, convert them, and deliver the new model to our customers within a much shorter time frame than if the models were manually recreated. In addition, the development of routines to interface with a TSS model has allowed rapid development of utilities to affect global changes for a TSS model. This routine has been used to rename all surfaces and/or optical properties to avoid conflicts when integrating a submodel into the spacecraft model. It has also been used to generate tables of optical properties and relevant surface properties for report generation. These routines will continue to be developed to handle more of the abstract, subtle differences between the codes and may eventually be expanded to a geometry builder/viewer capable of reading and writing any of the ASCII based geometry model formats.

7 Acronyms and Contacts

ASCII	American Standard Code for Information Interchange
EIS	Extreme Ultra-Violet Imaging Spectrometer
ESA	European Space Agency
ESARAD	European Space Agency Radiation Analyzer
ESATAN	European space Agency Thermal Analyzer
FEA	Finite Element Analysis
FEMAP	Finite Element Modeling and Post-Processing
IGES	International Graphics Exchange Specification
MetOp	Meteorological Operational Satellite
NASA	National Aeronautics and Space Administration
OMI	Ozone Measuring Instrument
SECCHI	Sun Earth Connection Coronal Heliospheric Investigation
SINDA	Systems Integrated Numerical Difference Analyzer
STEP	Standard for the Exchange of Product Model Data
STEP-TAS	Standard for the Exchange of Product Model Data for Thermal Models
TMG	Thermal Model Generator
TRASYS	Thermal Radiation Analyzer System
TSS	Thermal Synthesizer System

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